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Design of Smart Electrical Energy Meter with Theft and Consumption Report

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Abstract:

As energy demand all over the world continues to grow there is also an ever increasing intent by some utility customers to bypass their energy meters, an act referred to as energy theft; this contributes to the ATC&C (Aggregate Technical Commercial & Collection) losses experienced by distribution utilities, a situation that is worrisome and is responsible for the huge low return on investment to DISCOs (Distribution Companies) in Nigeria. This paper focuses on improving the functionalities of energy metring devices by upgrading them from just being STS (System Transfer Specific) one-way communication to AMI (Advanced Metering Infrastructure) two-way communication smart devices. The meter has added functionalities of real time tamper report and user consumption request via SMS. This is made possible with the introduction of micro switches to the chassis of the meter, conduit housing the entry cables and the dedicated report request button. This is implemented to trigger a connected PIC micro-controller in event of a change in any of their digital states as monitored by the micro-controller and instructions in software code using the C programming language. This product in practise will increase distribution utility company's investment on return as customers will be cautious not to engage in energy theft (Tampering of Meter installation).

Keywords **—Potential transformer, Current transformer, Micro-controller, Energy theft, Energy meter.**

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I. INTRODUCTION

This paper is aimed at improving the functionalities of a smart electrical energy meter. It is an embedded solution for electrical energy metering with the intent to optimize embedded system matrices. The meter should be able to report any tampering on the customers meter, as such distribution companies in Nigeria will have an automated report as regards energy theft in real time as against manual checks currently done.

The value of tamper detection increases rapidly, if the meter is part of an automatic metering management network, where the event can be reported quickly and appropriate action taken to investigate and correct the condition [1]-[3].

The 19th century was characterized with discoveries which set the pace for inventions and patents [8]. The first half of the 19th century brought brilliant discoveries in electromagnetism [4]-[5]. In 1920, the French Andre-Marie Ampere (1775-1836) discovered the electromagnetic action between currents. In 1827, the German Georg Simon Ohm (1787-1854) discovered the relationship between voltage and current in a conductor [6]. In 1831, the British Michael Faraday

(1791-1867) discovered the law of induction on which the operation of generators, motors and transformers are based [7]-[8].

With the invention of the dynamo Anyosjedlik in 1861 [8]. Werner von Siemens discovered the dynamo-electric principle in 1866. With the advent of the dynamo, it became possible to generate and distribute electrical energy cost-effectively and in large quantities [9]. It was not clear however, what the units billed should be, and what should be the most suitable measuring principles [8]-[9].

II. MATERIALS AND METHODS

PIC18F45K22

The PIC18F45K22 microcontroller is a microchip product. This family offers the advantages to all PIC-18 micro-controllers– namely, high computational performance at an economical price with the addition of high-endurance and flash program memory. On top of these features, the PIC-18 (L) F2X/4XK22 family introduces design enhancements that make these microcontrollers a logical choice for much higher performance and power sensitive applications [2]. Some of these features make it a good candidate for this research. EEPROM (electrically erasable programmable read only memory) can be use in storing useful information such as purchased energy unit, used energy, counter variables etc., the PORT-B interrupts work with the state of the micro-switches for reporting real-time energy consumption. Interrupt module is also used in setting up high and low priority interrupts and subtasks in software, it also works with its Enhanced Universal Synchronous Asynchronous Receiver And Transmitter module (EUSART) that will be used in conjunction with an on-board GSM (Global System for Mobile Communications) module used in reporting energy theft to a dedicated phone number.

Current Transformer

A current transformer is a type of transformer used in measuring ac (alternating current), it produces current at its secondary terminal that is proportional to that at its primary terminal. A current transformer is also referred to as an instrument transformer in that it basically transforms high current on its primary winding to a proportional low current value that can be easily processed and then applied to control devices like a relay and digital/logic devices. For example, microcontroller utilized in measuring applications like this smart energy meter. The standard current rating at primary winding for current transformers is usually 1-5A [1]-[3]. Equation 1 shows the relationships between the parameters of a current transformer, where Ns and Np are number of turns in secondary and primary windings in the current transformer respectively and Ip and Is are current in primary and secondary windings respectively.

$$\frac{Ns}{Np} = \frac{Vs}{Vp} = \frac{Ip}{Is} \tag{1}$$

From the fact that the secondary winding of a current transformer has more turns and looking at equation(1) we see that $(\frac{Ns}{Np} = \frac{Ip}{Is})$ here Ns is inversely proportional to Is and Np is also inversely proportional to Ip.

GSM Module

GSM Click is a product of Mikro-Electronika, it is a perfect solution for adding GSM/GPRS communication layer to a project. It features Telit GL865-QUAD quad-band (850/900/1800/1900 MHz) GSM/GPRS module. The board contains a TXB0106 6-bit bidirectional voltage-level translator as well as a SIM card socket. GSM Click communicates with the target microcontroller via seven mikroBUS™ lines (RX, TX, INT, PWM, CS, RST and AN). GSM click can use either 3.3V or 5V power supply [3]. GL865-QUAD V4 can be used for telematics applications where tamper-resistance, confidentiality, integrity, and authenticity of end-user information are required

[11]. This paper work utilized its SMS sending functionality in reporting energy theft (Tampering) and energy consumption to dedicated phone numbers that are part of the automatic metering management network saddled with the responsibility of responding to reports in real-time and also enable the Meter user to get His/her current energy consumption to user phone number.

The SMS functionality is based on the ISO/IEC 21989:2002 standards for Telecommunications and information exchange between systems. SMS enables a user to send and receive short messages to and from another user [12].

Micro-switch

The micro switch is the component that is engaged during an energy theft operation (Tampering); here it is connected to the microcontroller pin 36 (RB3). The switch has two basic states of ON and OFF which are easily tied to the digital states of 1 and 0 respectively, a change in state of the switch occurs when the seal on the Meter chassis is opened or when the conduit housing the service cable is forcefully opened by anybody.

Now in an event that the tamper button (linked to the micro switch) is in state 1 (ON) an SMS will be sent to a dedicated phone number that is part of the Automatic Metering Management Network, the PIC microcontroller routinely checks for this change of state on the micro-switch (tamper button) and then initiates the sending of the SMS over its TX pin RC6 (USART) when a tamper event is detected.

Potential Transformer

The potential transformer basically steps up or steps down voltage level. Potential transformers (PT), also called voltage transformers (VT), are a parallel connected type of instrument transformer. They are designed to present negligible load to the supply been measured and have an accurate voltage ratio and phase relationship to enable accurate secondary connected metering. The voltage at the secondary winding of a potential transformer can also be easily processed to suit control devices like relays and logic/digital devices like microcontroller.

From equation (1) we can see that the number of turns on any side of the transformer is directly proportional to the voltage on its respective windings; thus, a potential transformer could be a step-down or a step-up transformer depending on the number of turns on the respective windings.

This paper utilized a step-down transformer rated at [220:12V], here the secondary voltage when varied will give a proportional voltage at the primary winding which will be further processed by a rectifier circuit and a smoothing circuit then is fed to the microcontroller at a dc voltage that can be easily processed by the later.

III. SIMULATION OF ENERGY METER

Every measurement system is designed to take on specific inputs, process them and give a proportional value of the input as output in a specific format. This paper work will take as input the voltage across and the current through a consumer's load, process them and step them down to proportional values that are easily manipulated for a microprocessor-based application. Subsequently, the consumed energy is calculated in by the software and displayed on a liquid crystal display. Any theft attempt is captured by a change in the digital states of the micro-switch and a report already in the software is sent via GSM network.

Measurements needed

Current through the customer load, Voltage across the customer load, Active Power measurement.

Current measurement

The specification of the current transformer in use is in the ratio [100:1] A, this will provide 1A of current at its output if the load through the input consumes 100A and will have 0.5A on the primary side if the load pulls current of 50A. From this it is shown that the multiplier is 100.

Since PIC micro-controllers take dc voltage between 1-5V as input and not current, therefore, the output of the current transformer which is a lower proportional value of the current through the consumers load needs to be converted to a proportional current value within 1-5A and through computational algorithm in software the exact value of current through load at the primary terminal of the current transformer is calculated and saved as a variable in the software code for further computational use.

This was achieved via a burden resistor placed across the output of the secondary terminal of the current transformer, here two things are involved: first the current through the burden resistor is a proportional value to that flowing through the consumers load at the primary windings and secondly, since voltage is required to be feed into the microcontroller, with the burden resistor across the secondary terminal of the current transformer the voltage across the burden resistor will be feed as input to the analogue port of the microcontroller. From simulation using a dc motor load, the ac voltage across the secondary windings is so small that its peak value is lesser than 5V as such there is no need for rectification, rectification is needed however in a hardware implementation since some loads may consume more current and then the ac voltage across the burden resistor may have a peak value which may be greater than 5V which will permanently damage the PIC micro-controller. This wasobtained from Ohms law

$$v = i * z \qquad (2)$$

where z is the impedance of the load as most loads are inductive or capacitive

$$i = \frac{v_{peak}}{z} \qquad (3)$$

Also knowing that

$$V_{rms} = V_{peak}/\sqrt{2} \qquad (4)$$

Voltage measurement

A 220:12V voltage ratio specification is used for this work, it is obviously a step-down transformer. Now the voltage across the consumers load will have its proportional voltage level across the secondary windings of the voltage transformer; a voltage of 12V at the secondary terminal depicts a voltage of 220V across the primary terminal. Since the microcontroller requires at most 5Vdc of input voltage there is need to further process the secondary winding voltage to meet the requirements of the microcontroller.

The processing starts by rectifying the ac voltage to dc using a bridge rectifier circuit comprised of four IN4001 diodes. after rectifying the ac voltage there are some ripples of ac component therefore a smoothing capacitor of 470uF is placed across the output of the rectified signal: with this a steady dc voltage free of ac component is available as shown in Fig.1 below with a value of 15.3V dc. Since this voltage cannot be directly feed into the microcontroller, a voltage divider circuit is provided which provides 3.06V across the 100K resistor: in some applications a Zenner diode will do just fine. This is now the input voltage will be feed into the analogue port of the microcontroller. It should be noted that this voltage varies between$0 - 3.06$V.

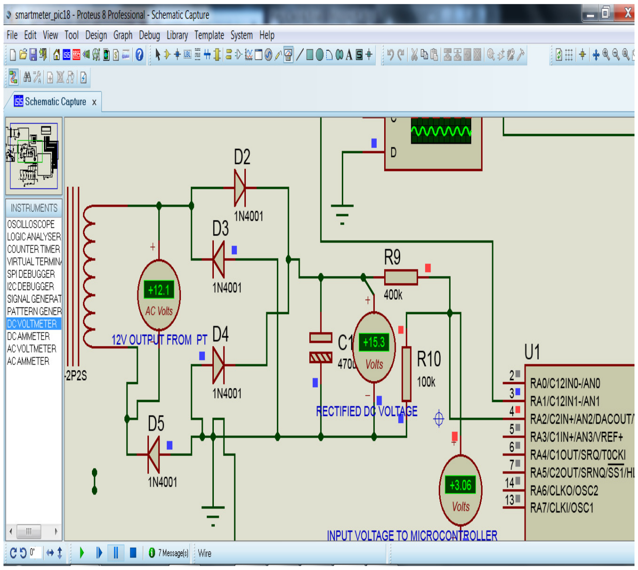

Fig.1. showing how the voltage at the secondary winding of the PT is processed to suitable scale for microcontroller application.

Power measurement

A smart energy meter just like every other energy meter measures the electrical power consumed by a load over time in a periodic manner except there is no load consuming power at that time. The unit of measurement is the KWH (Kilowatt hour). From this unit it is seen that the electrical energy is a product of two basic units: watts and time. Looking into the watts which is also a product of three units: voltage, current and power factor, there was success in getting the current and voltage into the microcontroller, and the need to assign a valuefor the power factor. In this paper, an assumed power factor of 0.9 was used. Now, the other unit of time is in hours which is equivalent to 60 minutes or 3600 seconds. If power consumed is not up to an hour then measurement is in fractions of the basic unit of time hour.

Where active power consumed over time

$$p = i * v * t * \cos \qquad (2)$$

Where, cos   is assumed to be 0.9, i = current and v = voltage.

From Fig.2 the consumed energy of the dc motor after 10 minutes (0.166667 hours) is 0.093KWH as displayed on the LCD (liquid crystal display).

From equation (5), substituting for values; $i = 0.07, v = 12, t = 0.166667$ and $pf = 0.9$, we have

Energy= 0.126KWH.

Percentage error in measurement was evaluated below.

$$Tv = True\ value\ and\ Sv = Simulation\ value$$

$$\frac{Tv - Sv}{Tv} * 100\% \qquad (3)$$

$$\frac{0.126 - 0.093}{0.126} * 100\% = 26\% \qquad (4)$$

Thus, the error in measurement from the simulation is 26%. This variation is attributed to time delays: the time it takes the LCD to initialize and update information, the speed of PC, the assumption that the dc motor is purely resistive against the fact that it is a capacitive load and the assumed power factor of 0.9.

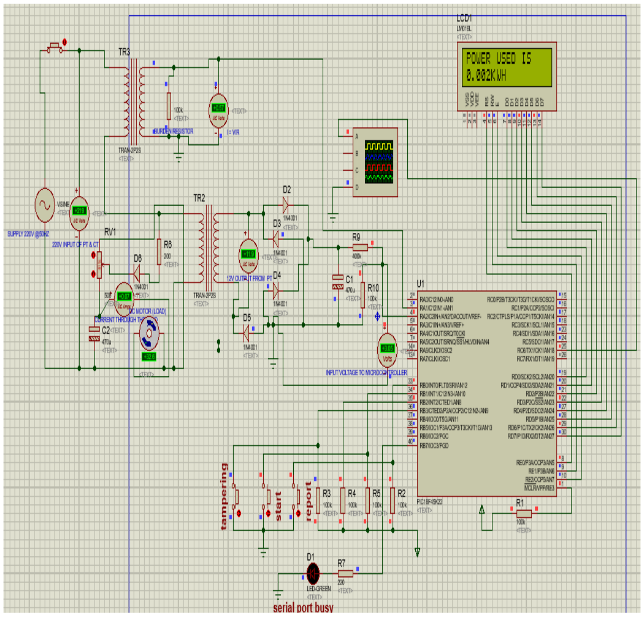

Fig. 2. Simulation diagram showing the PIC18f45k22 microcontroller interfaced with other components as described in paper.

IV. CONCLUSIONS

Further works should be carried out to meet industry best standards especially the automatic metering management network frame work. This frame work should take into considerations the fact that GSM network may not be available round the clock as such better and more reliable telecommunications options such asfourth generation (4G) orfifth generation (5G) radio frequency (RF) transmission should be considered so as to take care of areas where GSM network is not available.

The error in measurement from the simulation is 26%. This variation is attributed to time delays: the time it takes the LCD to initialize and update information, the speed of PC, the assumption that the DC motor is purely resistive against the fact that it is a capacitive load and the assumed power factor of 0.9.

This work can also be built using the real components as specified, tested in real time and deployed to the Nigerian market to contribute to the ongoing Meter Asset Provider (MAP) exercise by Nigerian Electricity Regulatory Commission (NERC).

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